FUTURE FAR-IR AND SUBMM TELESCOPES: POTENTIAL FOR NEW DISCOVERIES

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- These wavebands currently suffer from:

  Lack of spatial resolution – λ/D

  Lack of sensitivity / field of view – $h\nu$ vs kT

- Interferometry possible, but arrays quite small

- Can probe ISM astrophysics in great detail, but most opportunities for discoveries at highest z

- Future telescopes will address:

  Energy generation history to z$\simeq$3 (SIRTF)

  Details of galaxy astrophysics there (ALMA)

  First pollution of Universe at z$\gtrsim$15 (ALMA)

  Fair selection of high-z galaxies z (ALMA)

  Redshifted stellar/SN light from z$\gtrsim$20 (SPECS?)

  SZ/OV effect from (pre-)reionization? (ALMA)

RESOLUTION & SENSITIVITY

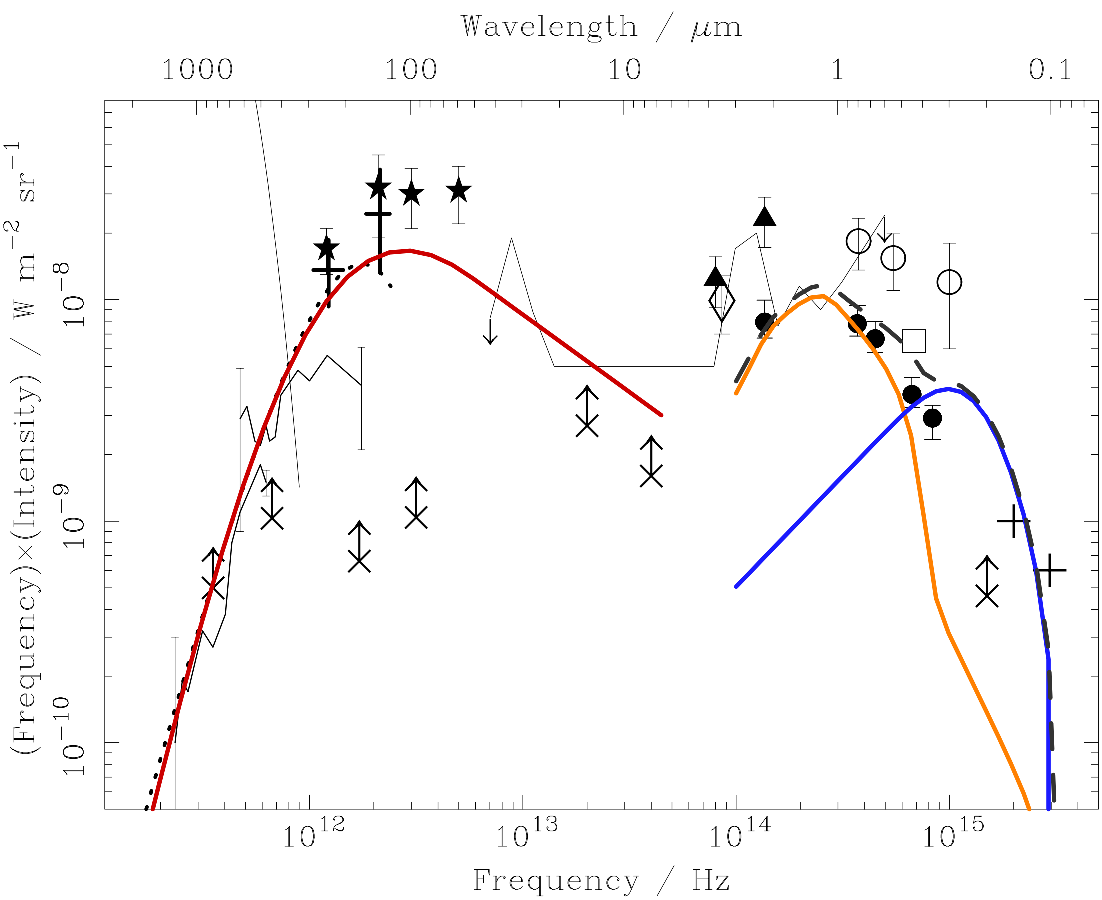
- ISO and SCUBA enabled moderate/high-z far-IR sub-mm astronomy possible
- Both limited by resolving power – confusion
- OVRO/IRAM/BIMA/Nobeyama arrays can only detect brightest SCUBA galaxies, in 10s of hours
- SIRTF too is quick to reach confusion in far-IR
- Ideally, must obtain sub-arcsec resolution, to avoid confusion limit. Requires aperture/baseline $D > 250[\lambda/\mathrm{mm}]$ m
- A variety of requirements for the next step:

  – Ability to resolve high-z galaxies quickly: ALMA, far-IR interferometers

  – Wide-area, deep surveys to select targets: 10–50-m (sub)mm telescopes with large arrays, SIRTF, Herschel, smaller future missions

  – Rapid wide-band CO redshift searches: ALMA and dedicated mm instruments (Glenn, Bock)

BACKGROUND RADIATION



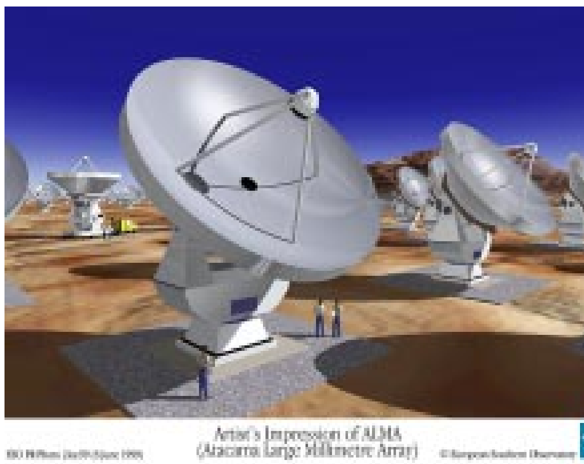
Compare optical/UV and far-IR/sub-mm bands

Star/AGN light reprocessed by dust

Dramatic progress in last 3 years:

- COBE-FIRAS/DIRBE in sub-mm & far-IR
- Agreement on optical/near-IR spectral shape
- SCUBA & ISO lower limits
- Uncertain 5-200 μm region (SIRTF/SOFIA)

SUITABLE (SUB)MM TELESCOPES

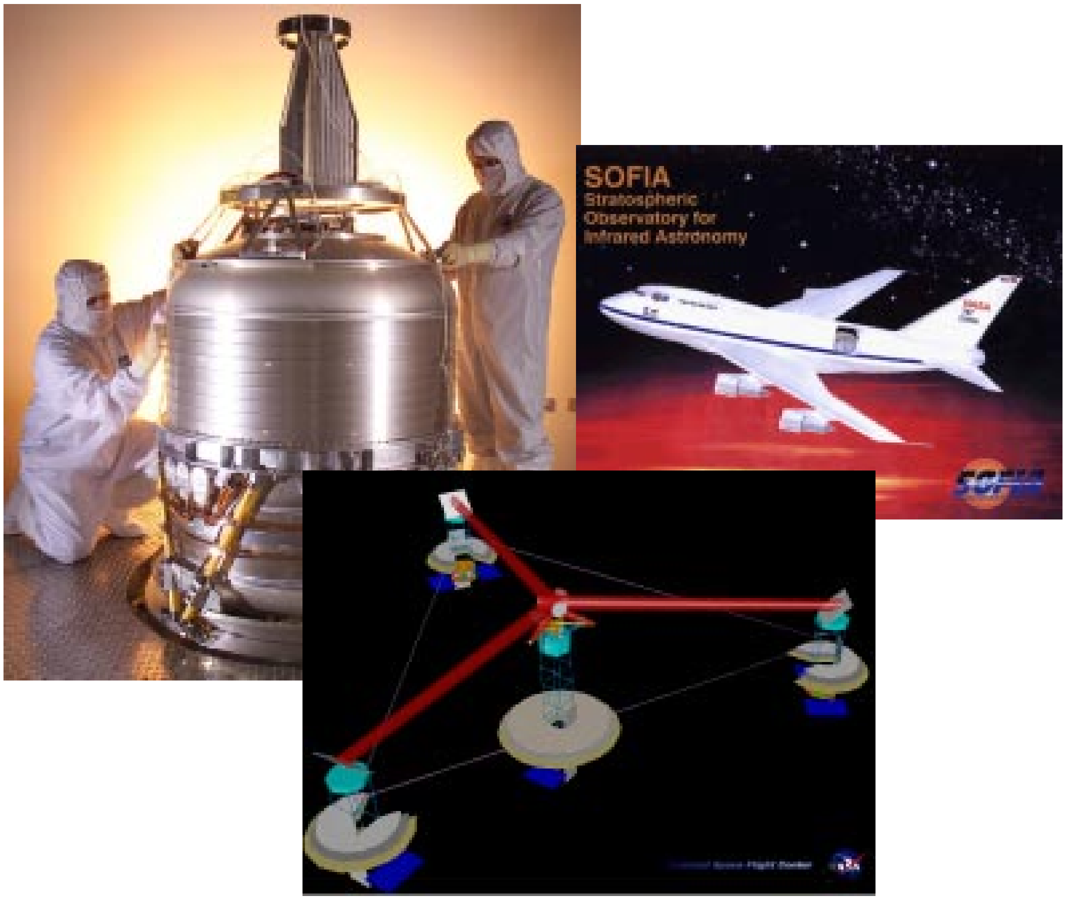


For 1-σ, 1 deg^2, 1 hour, 850 μm:

- SCUBA: 50-100 mJy beam^{-1}, 13 arcsec
- ALMA: 1-10 mJy beam^{-1}, 0.01-3 arcsec
- FIRST*: 50-100 mJy beam^{-1}, 25 arcsec
- BLAST**: 30 mJy beam^{-1}, $\simeq$30 arcsec
- Planck†: 7 mJy beam^{-1}, 4 arcmin
- SOFIA: >100 mJy beam^{-1}, 40 arcsec
- LMT/GTM:^{M} 1.5 mJy beam^{-1}, 6 arcsec

*450 μm; **350 μm †All-sky survey ^{M}1.1 mm

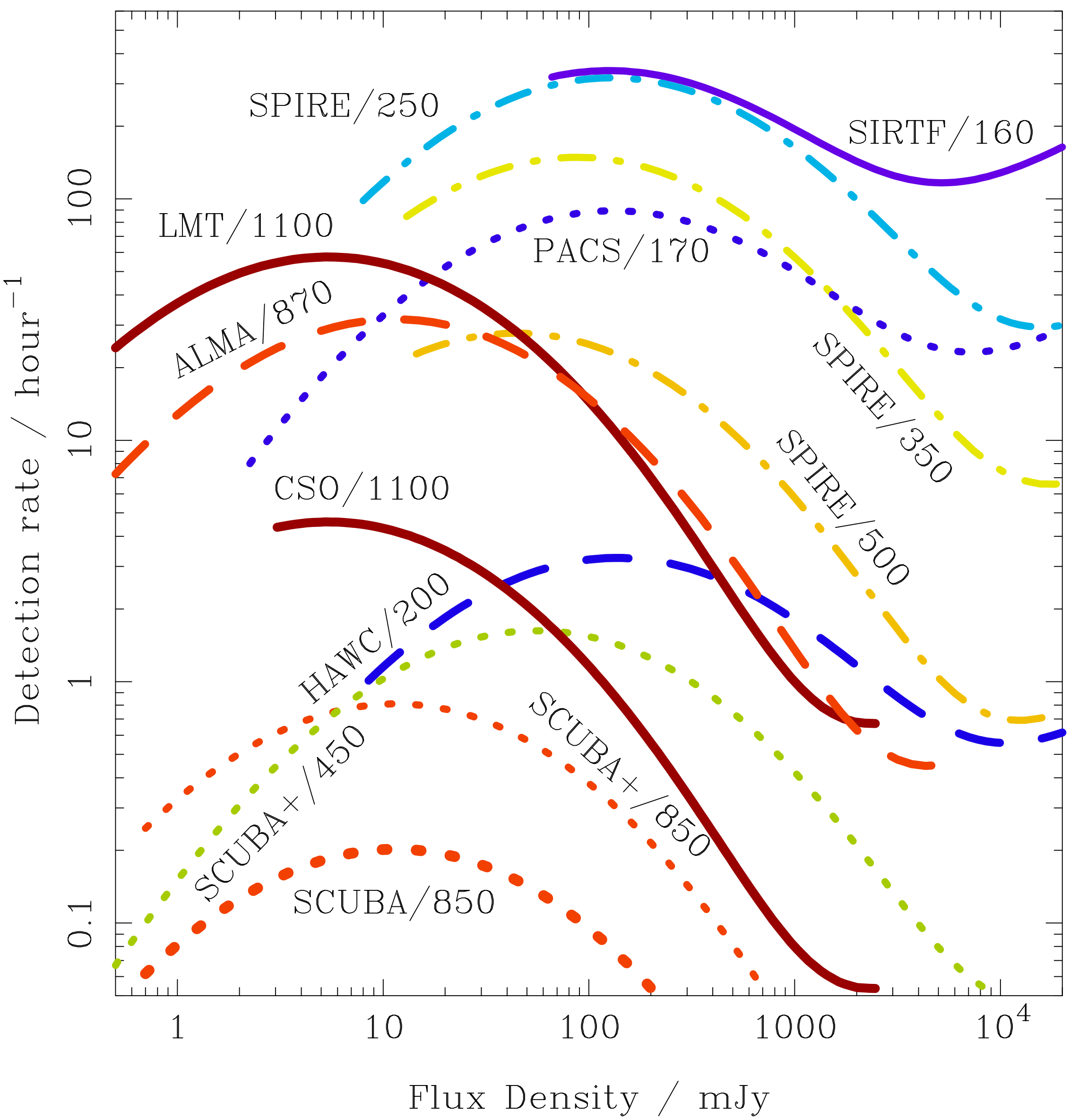
SUITABLE FAR-IR TELESCOPES



For 1-σ, 1 deg^2, 1 hour:

- SIRTF(160 μm): 11 mJy beam^{-1}, $\simeq$40 arcsec
- SIRTF(70 μm): 0.9 mJy beam^{-1}, $\simeq$18 arcsec
- SIRTF(24 μm): 0.4 mJy beam^{-1}, $\simeq$7 arcsec
- SOFIA(110 μm): 240 mJy beam^{-1}, $\simeq$10 arcsec
- SPECS (250 μm): 30 μJy beam^{-1}, 0.05 arcsec

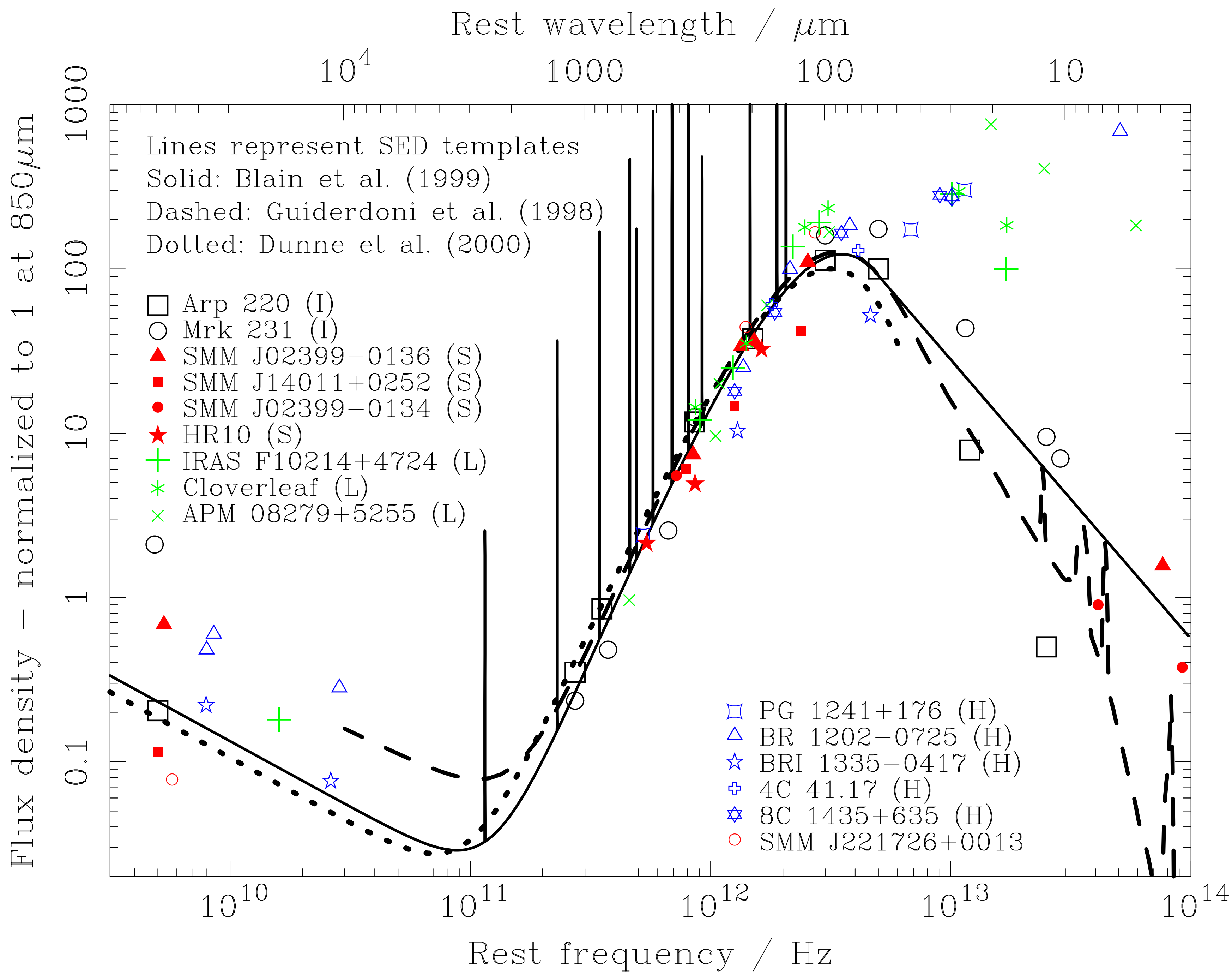
FUTURE DETECTION RATES



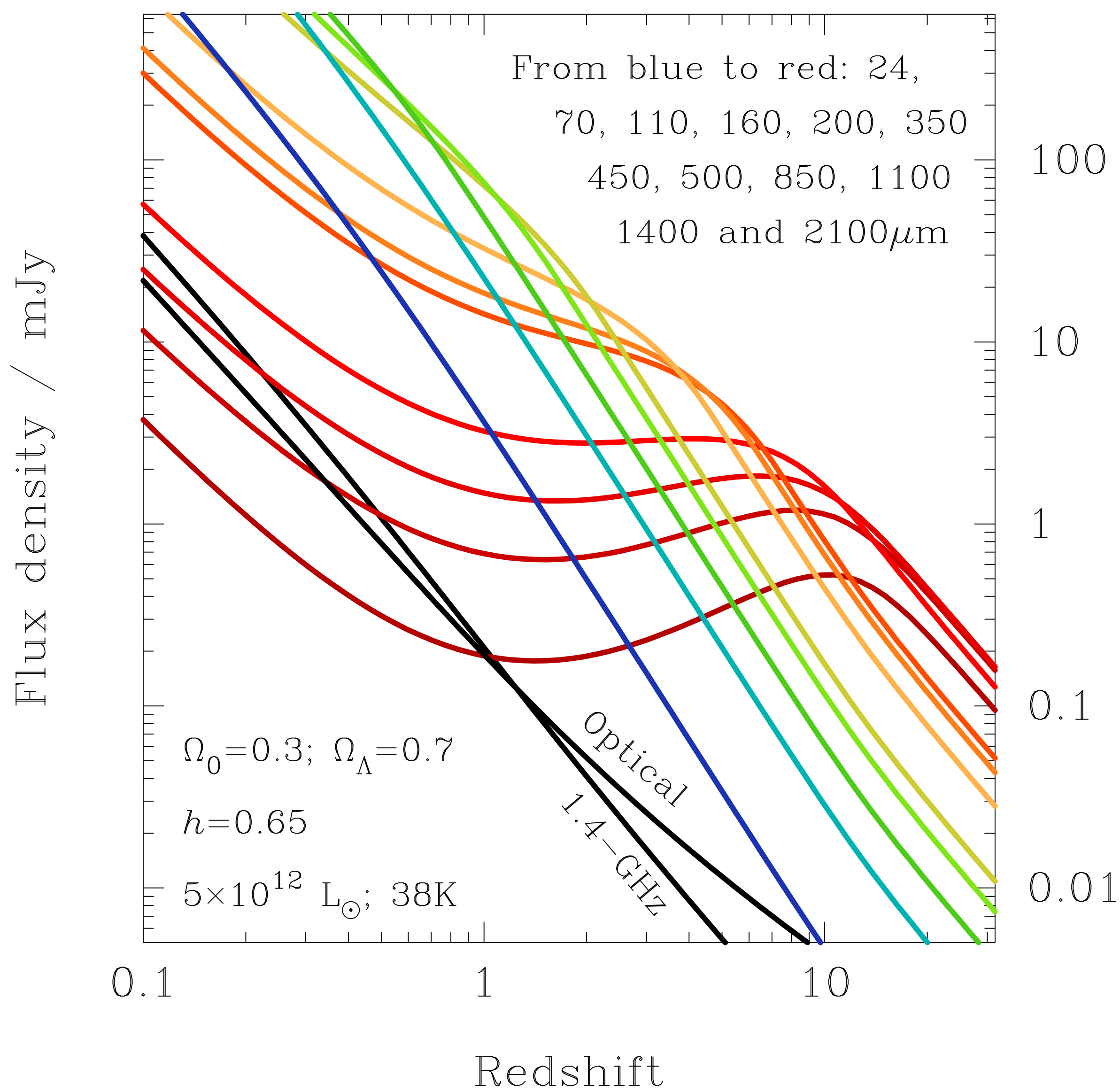
- Shows range of forthcoming instruments
- ALMA crucial for any extremely deep survey and for direct follow-up
- Note also the huge Planck sample

DISCOVERIES USING SIRTF/ALMA/Herschel...

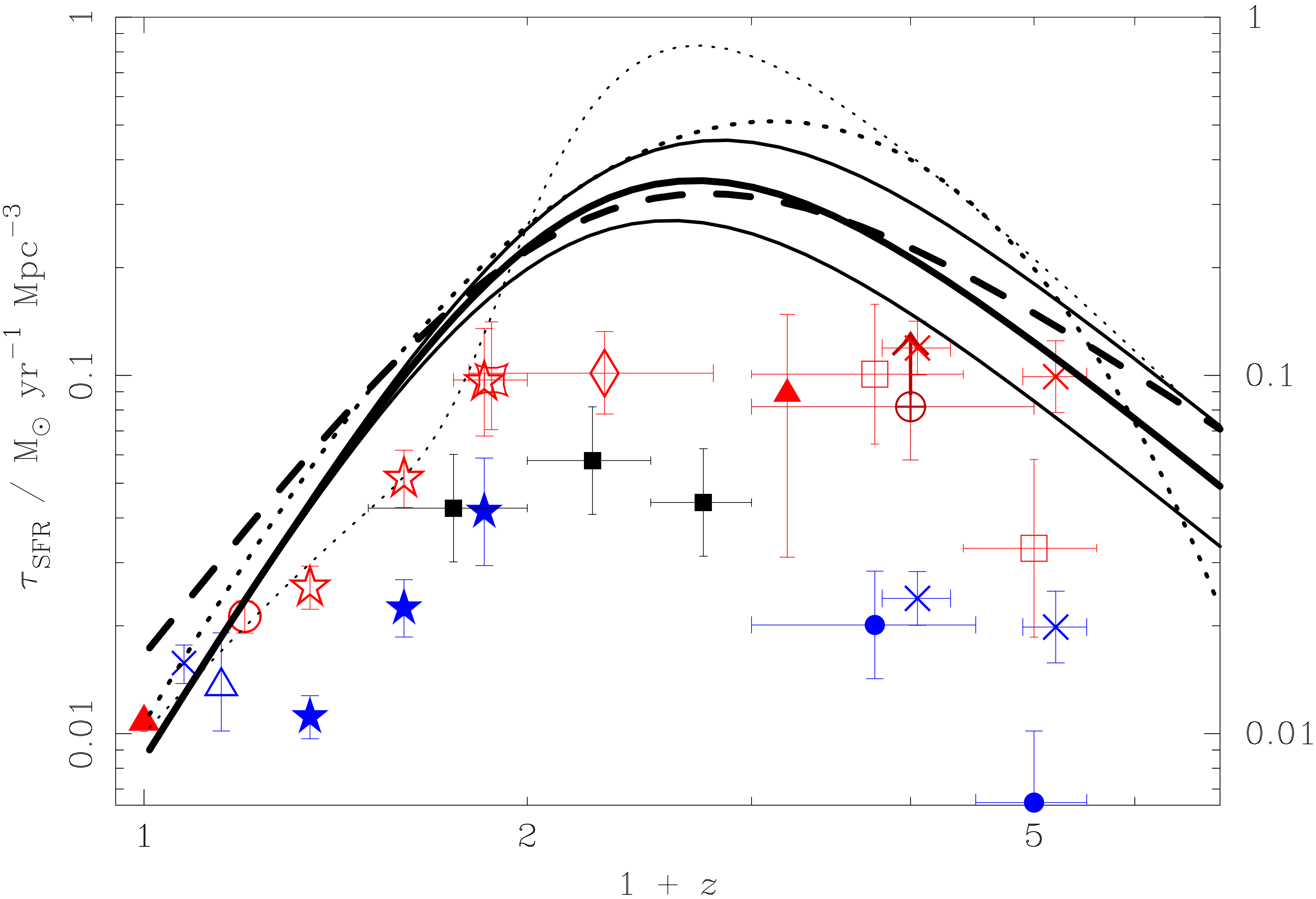
- SIRTF will make statistical surveys at $z \simeq 1$–2
- ALMA detects known sub-mm sources in seconds
- With no confusion ($< \mu$Jy level), ALMA reaches two orders of magnitude deeper than SCUBA
- Can find sub-L^* galaxies at moderate z, or the most distant objects
- SIRTF/Herschel/future (sub)mm bolometer arrays scan the sky faster, and can feed ALMA targets
- SOFIA/Herschel spectrographs probe mid-/far-IR wavelengths too short for ALMA
- Will ALMA run out of dusty sources at some z? Or will CMB control high-z dust temperature?
  - Yes: need a way to probe more distant objects
  - No: need to study ALMA sources at SED peak
- Need to return to mid-IR for redshifted starlight? SPECS – SEDs of high-z galaxies & (pre-)reionization



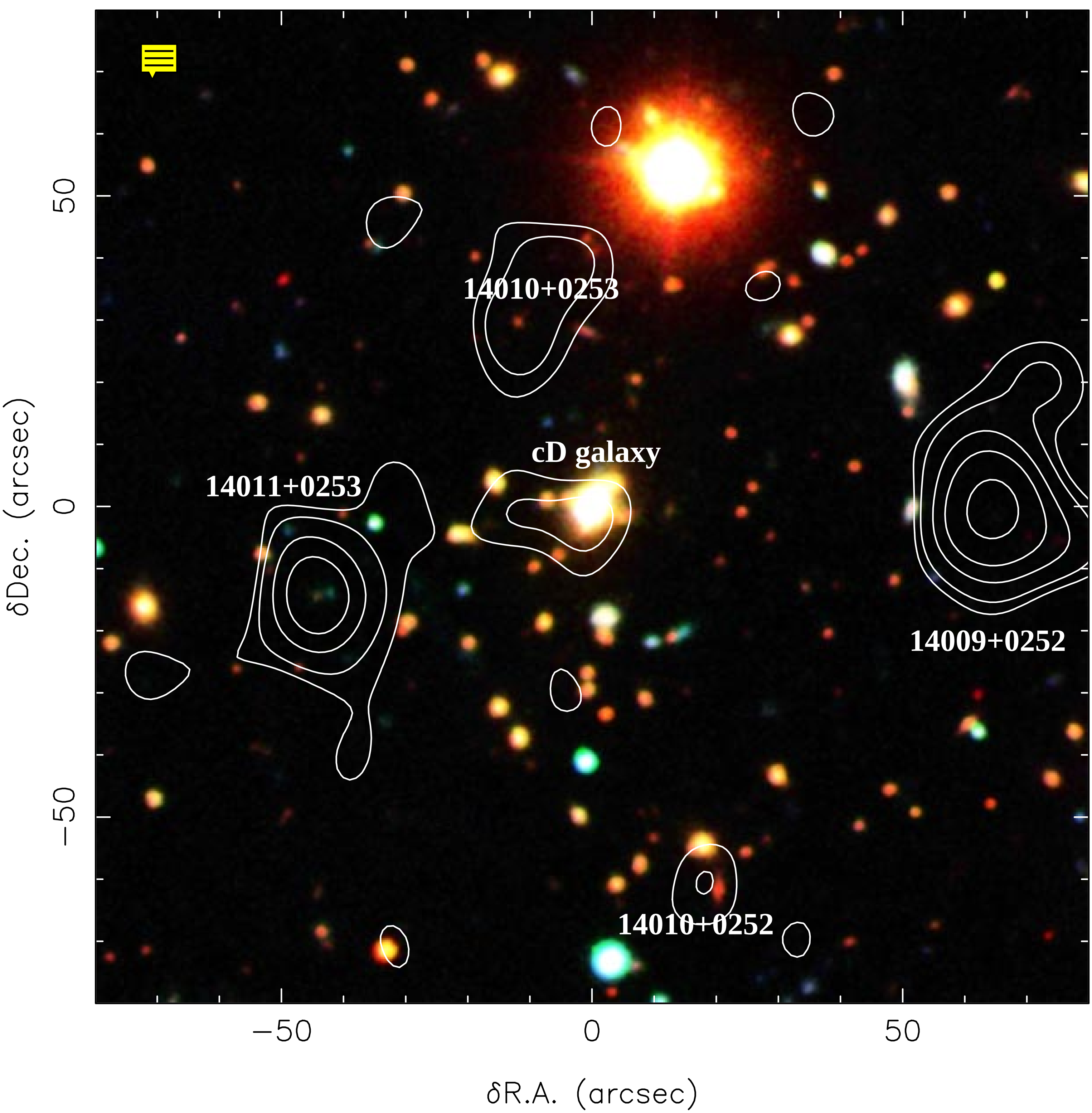
Rest wavelength / μm
10^4
1000
100
10
Flux density − normalized to 1 at 850μm
1000
100
10
1
0.1
Lines represent SED templates
Solid: Blain et al. (1999)
Dashed: Guiderdoni et al. (1998)
Dotted: Dunne et al. (2000)
Arp 220 (I)
Mrk 231 (I)
SMM J02399−0136 (S)
SMM J14011+0252 (S)
SMM J02399−0134 (S)
HR10 (S)
IRAS F10214+4724 (L)
Cloverleaf (L)
APM 08279+5255 (L)
PG 1241+176 (H)
BR 1202−0725 (H)
BRI 1335−0417 (H)
4C 41.17 (H)
8C 1435+635 (H)
SMM J221726+0013
10^10
10^11
10^12
10^13
10^14
Rest frequency / Hz



From blue to red: 24,
70, 110, 160, 200, 350
450, 500, 850, 1100
1400 and 2100μm
Ω0=0.3; ΩΛ=0.7
h=0.65
5×10^12 L⊙; 38K
Optical
1.4–GHz
100
10
1
0.1
0.01
0.1
1
10
Flux density / mJy
Redshift

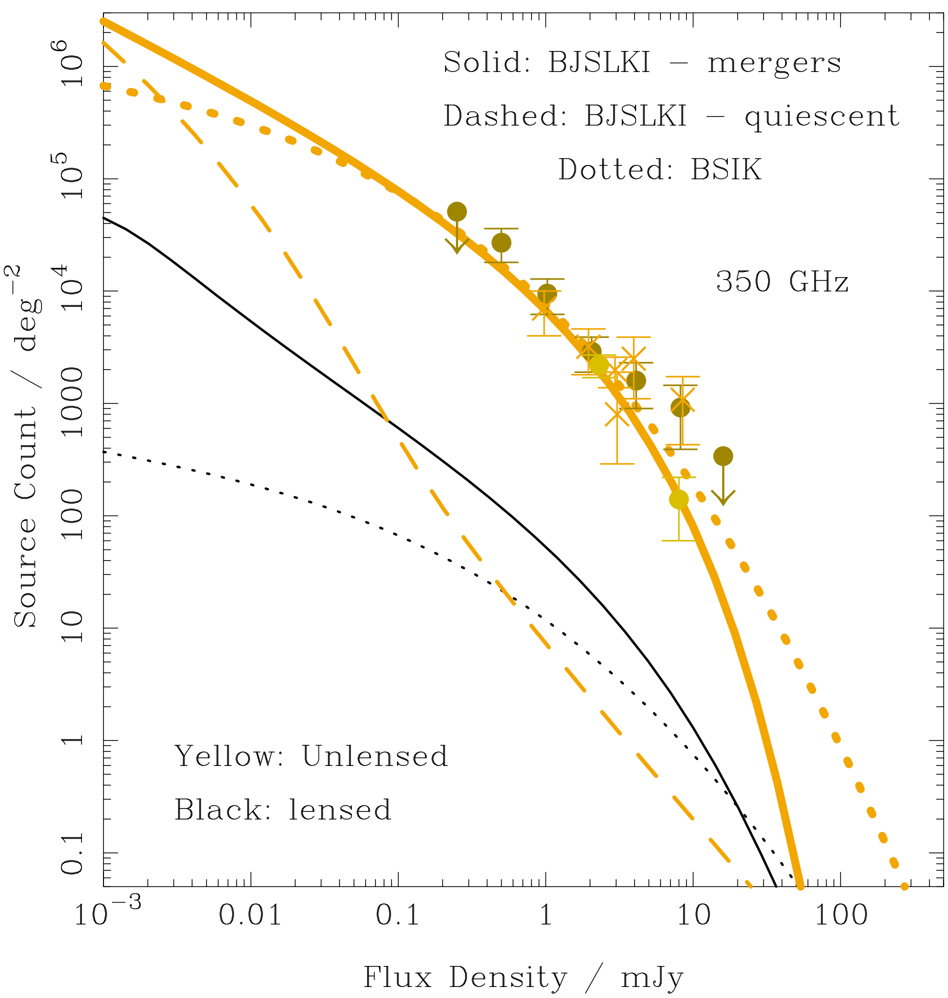


1
0.1
0.01
τ_{SFR} / $M_\odot$ yr^{-1} Mpc^{-3}
1
2
5
1 + z



14010+0253
cD galaxy
14011+0253
14009+0252
14010+0252
δDec. (arcsec)
δR.A. (arcsec)
50
0
−50
−50
0
50

VERY DEEP SURVEYS AT 350 GHz



- Data from all published SCUBA surveys
- Continuum models again, plus lensed galaxies
- The quiescent galaxies could steepen faint counts
- In 160 hrs ALMA can reach 20 μJy (5σ) in a 2×10^{-5} deg^2 area

MORE EXOTIC TARGETS

- Maybe discovery potential lurks in the exotic?
- 0.67-μm Li recombination at z $\sim$ 500 (Loeb)
- LiH emission [J(1$\rightarrow$0) at 444 GHz] from high-redshift IGM/'protogalaxies'
- Important issues clearer after ALMA/NGST:
  - Know something about z$\sim$10
  - Does UV or far-IR emission dominate at z$\gtrsim$4?
  - Know about very faint 'foreground' galaxies
- SZ effect is redshift-proof. Search with ALMA, or dedicated GHz array (Carlstrom)
- Very high-z H/D/Li lines appear in radio – SKA
- GRBs could be detectable from the highest z. Afterglows peak in far-IR, but redshift (sub)mm
- CMB surprises might turn up in (sub)mm

SUMMARY

- Sub-arcsec resolution required – both to avoid confusion, and study internal structure of sources

- Galaxies at $z \lesssim 3$ will be studied using SIRTF; SOFIA/Herschel/ALMA follow-up

- ALMA should find earliest metal-enriched objects

- ALMA may determine epoch of first enrichment or epoch of first light – test with NGST

- CMB reduces ALMA's efficiency at $z \gtrsim 10$

- If first light beyond $z = 20$, SPECS may image it directly & study all lower-z objects in great detail

- Arcmin-scale structures on the CMB could reveal details of re-ionization via mm-wave SZ effect

- Exotic high-z molecular line observations?